

Neutrino Oscillations at the Intensity Frontier: The NOvA Experiment

Athanasios Hatzikoutelis

Physics Department
University of Tennessee Knoxville
USA

a.hatzikoutelis@utk.edu

Abstract. The “NuMI Off-Axis electron-neutrino Appearance” (NOvA) is a second generation, long-baseline, neutrino oscillation, experiment. It is made of two detectors, a large Far detector (14 ktons) and a similar Near detector (222 tons), both made of mostly active scintillator and separated by 810 km. Along with the 700 kW NuMI-beam upgrade (a prelude to the Intensity Frontier), it will be the leading neutrino experiment at Fermilab. In the wake of the recent measurement of the θ_{13} mixing angle, NOvA is positioned to see evidence of the neutrino mass hierarchy, possibly to resolve the θ_{23} octant ambiguity, and begin the study of the CP violation at the lepton sector. The experiment is under construction. The design and potential of this experiment is presented here along with the current status.

1. Introduction

The last two years have been an exceptional time for neutrino physics. Several experiments have measured for the first time a non-vanishing value for the mixing angle θ_{13} . They are accelerator driven electron-neutrino appearance like the Japan-based T2K [1] and the USA-based MINOS [2] or nuclear reactor driven anti-neutrino disappearance, ones like the China-based Daya Bay [3], with strong evidence of reactor electron antineutrino disappearance consistent with neutrino oscillations and the France-based Double Chooz [4] with the most recent measurements to date. They progressively defined the value of θ_{13} to within a non-zero value-band around 9° at various confidence levels each (based on their systematics and the assumptions in the calculations). This large value makes it more possible now to explore CP-violation and the mass hierarchy. Now, we may be able to address some of the compelling questions of neutrino physics and the lepton sector. What is the neutrino mass hierarchy? Do neutrino oscillations violate CP symmetry? Is the θ_{23} mixing angle 45° (maximal)? Do these findings indicate new symmetries or new selection rules, forces, sectors?

The community has come together in several instances over the past few years trying to decide on the path for the next generation and further in the future experiments. Work on the Frontiers in physics of Intensity, Energy and Cosmic, will provide the answers or better yet will over constrain the above parameters in order for us to be able to determine if there is any new physics beyond the Standard Model.

2. The NOvA Experiment

The second generation of long baseline accelerator base neutrino oscillation experiments is made of three experiments; the already running MINOS from Fermilab, the T2K from JPARC at 293 km, and the NOvA Experiment also from Fermilab at 810 km. The NOvA experiment aims to lead in the measurement of appearance of electron neutrinos and anti-neutrinos from the NuMI (Neutrinos at the Main Injector) neutrino beam at Fermilab (Fermi National Accelerator Lab in Batavia, Illinois, USA). The NOvA neutrinos are produced by a 120 GeV proton accelerator complex at 400 kw with a planned upgrade to 700 kw. After the protons fall on a graphite target, a secondary beam of pions and kaons is focused with magnetic horns that can control the beam focus and through the polarity of the pulsating current they can control the consistency of the tertiary neutrino beam. Beyond the beam, the experiment is

made of two functionally identical detectors positioned off-axis by 14 mrad. This angle yields for the resulting neutrino energy spectrum a much tighter distribution compared to an on-axis orientation (fig.1). The reduced flux is peaked about 2 GeV within 20% and tuned for the first oscillation-maximum.

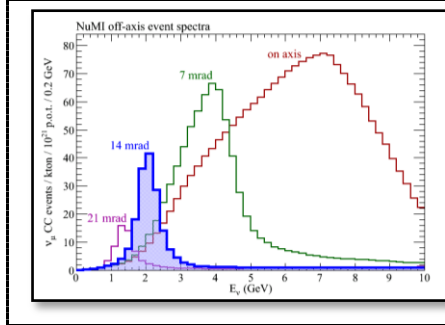


Figure 1. Energy spectrum of the off axis technique yielding a narrow band around 2 GeV for the NOvA neutrino beam.

2.1. NOvA Detector Design

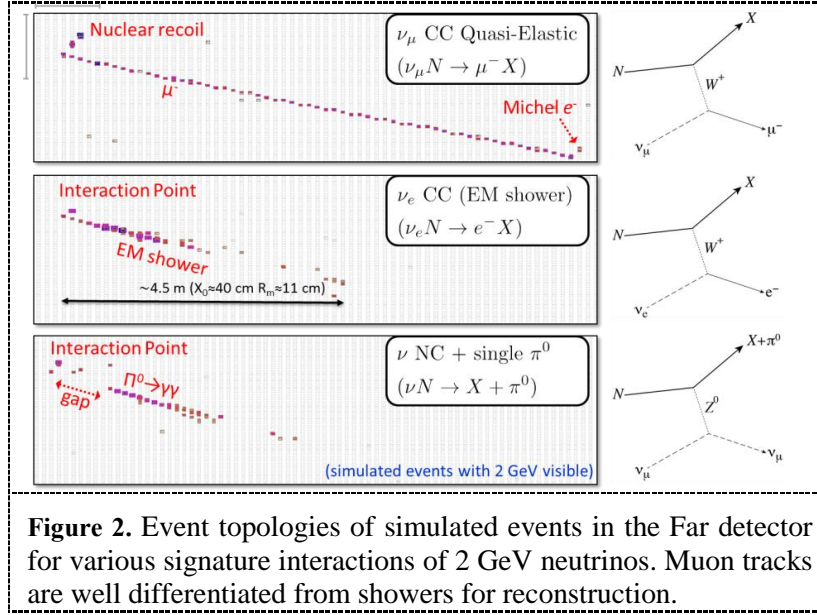
The design of NOvA is based on long extruded PVC tubes/cells, 4x6 cm cross-section, with a length of 15 m for the Far and 4 m for the Near detector. They are filled with a mineral oil liquid scintillator instrumented with a single wavelength shifting fiber each that is read out by an Avalanche Photo-Diode (APD). This creates a 64% active material, low-Z calorimeter with a radiation length of $X_0 \sim 38$ cm and tracking capabilities. This technology is optimal for electromagnetic shower reconstruction as well as muon tracking.

The near detector design is for about 18,000 such cells, totaling 300 tons, positioned at a distance of 990 m from the NuMI beam target. The Far detector is much larger, numbering about 370,000 cells for 14 ktons, and at a distance of 810 km located in Ash River, Minnesota.

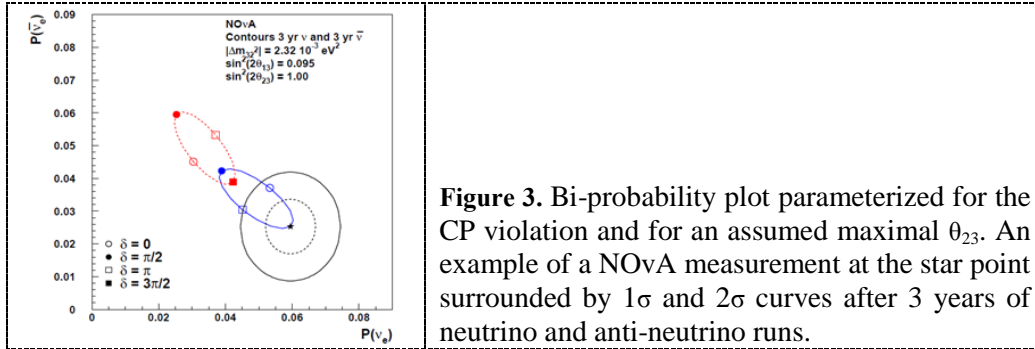
The detectors are instrumented by regions. They are synchronized and readout at high speed, continuously and with no dead time. The threshold is set to a half of a minimum ionizing particle energy deposition at the far end of the longest cells, which is equivalent to an energy threshold of about 6-8 MeV. All of the data is buffered in a large computing farm and triggered on asynchronously by the DAQ and Accelerator Trigger Systems. In figure 2, there are event displays of some indicative simulated event topologies of the Far detector response to the prominent signatures of the NOvA experiment. A 48% reconstruction efficiency of 2 GeV electron-neutrinos from charge-couple quasi-elastic scattering and a 1% rate of fake neutral-current interactions with the proton recoil visible to few MeV make the NOvA detection system an exceptional detector for its size.

2.2. The NOvA measurement

The NOvA experiment is designed to measure independently four probabilities of oscillation between the muonic and electron neutrinos as they travel from the Near detector site to the Far detector 810 km away. It will combine the measured probabilities to evaluate the θ_{13} and θ_{23} . Through these, it will attempt to determine the mass hierarchy and the octant of the θ_{23} . It may even be able to see the first evidence of CP violation in the lepton sector.



Accepting the value for the $\theta_{13} \sim 9^\circ$, we can parameterize the bi-probabilities of appearance measured at the NOvA experiment in the plot of figure 3 between assumptions of θ_{23} and all the values of the CP-violating parameter. The plot assumes that the θ_{23} is maximal. A NOvA measurement is represented by a star in the plots. The curves around it represent 1σ and 2σ resolution after a 3 year run with neutrinos and anti-neutrinos each. The measurement star will fall on one of the symbols representing the CP violation case and on a curve representing the mass hierarchy. Depending on that point, the NOvA may be able to resolve the hierarchy with up to 2σ resolution and indicate the extent of CP violation (see fig. 3).



2.3. NDOS prototype

The Near Detector On the Surface (NDOS) is the prototype of a NOvA Near detector. The NDOS was built for component production, installation and integration experience within the project and has been completed since May 2011. It is positioned at a crossing of the beams from both the Main Injector (110 mrad off axis) and the Booster accelerators (on-axis but 23° rotated). It is also situated 100 m above the beams (i.e. on the surface). Until May 2012, it was doing physics runs when the NuMI beam was shut down for the upgrade and it is planned to pick up again after NuMI beam resumes in April 2013. In the

meantime, it does engineering runs that assist in evaluating hardware and software technologies and techniques on it. The data acquisition and the detector control systems (hardware and software) have been using the NDOS as a life size test-stand for their developments. APD technologies are currently being evaluated before being widely deployed on the Far detector in the Fall of 2012. The track and vertex reconstruction software have been using the NuMI and Booster beams to create extensive libraries of good events, as well as the cosmic muons for background rejection algorithms. All these events were used to calibrate the detector response by measuring the attenuation length in the cells and the spectrum of Michel electrons that give us access to the exceptional resolution and low readout thresholds.

3. Current Status of NOvA

The Far detector laboratory was completed and the NOvA project got beneficial occupancy since April 2011. It is located at Ash River, Minnesota. It is on the surface with 3 m earth equivalent overburden above the detector hall. The detector construction has started as of late summer of 2012. Construction of the full 14 ktons detector is expected to be completed in 2014. The Near detector cavern is being prepared and the detector completion is expected by 2014 as well. The NuMI beam upgrades are on schedule to begin delivering the new beam power by the accelerator restart in Spring of 2013.

4. Summary

The next decade will be the time that some of the most important questions of neutrino physics may be answered. The NOvA experiment will be in the position to answer some of them, like the octant of θ_{23} and maybe the mass hierarchy, if it is running at least for 3 years on neutrino and anti-neutrino beams. Most importantly, it may even be in a position to show some first evidence of the CP violation in the lepton sector. The experiment is well prototyped by now and well understood. It is also on track in construction for the Far and Near detector and the beam upgrades will provide it with the best chance to lead the way in understanding the lepton sector and beyond.

References

- [1] K. Abe et al., Phys.Rev.Lett. “T2K” 107, 041801 (2011), 1106.2822.
- [2] P. Adamson et al., “MINOS” Phys. Rev. Lett. 107, 181802 (2011), hep-ex/1108.0015v1.
- [3] F. P. An et al, “Daya Bay” PRL 108, 171803(2012), arXiv:1203.1669 [hep-ex].
- [4] Y. Abe et al, “Double Chooz ”arXiv:1207.6632v1[hep-ex] 27 A July 2012,
DC first indications arXiv: 1112.6353[hep-ex] 13 March 2012.
- [5] Neutrino Experiments at the Intensity frontier: <http://if-neutrino.fnal.gov/neutrinos.pdf>